# Rainfall hasard assessment: a geostatistically based methodology

## Estimation de l'alea pluviométrique : une approche géostatistique

Leblois E.[1], Ramos M.H. [1], Guillon A. [2]

[1] Cemagref, 3 bis quai Chauveau 69336 Lyon Cedex 09
[2] Conseil Général des Hauts de Seine, Direction de l'Eau

Email : leblois@lyon.cemagref.fr or aguillon@cg92.fr

## RESUME

Le point de départ de notre travail est une requête de la Direction de l'Eau du département des Hauts de Seine (France) qui souhaite garantir à tous les habitants un même niveau de protection vis-à-vis des crues dues à des pluies intenses.

*Ceci oblige à évaluer le fonctionnement observé du système d'assainissement pluvial en tenant compte de la sévérité des pluies passées, et amène à traiter les questions scientifiques suivantes : comment juger de la sévérité d'un événement pluviométrique observé ? Peut-on résumer par un seul indicateur l'ensemble des pluies fortes d'une année ? Tel est l'objectif de la présente contribution, rendue possible par les travaux antérieurs de (Ramos et al., 2005 et 2006).*

## ABSTRACT

This study investigates an operational request of the Water Direction of the Hauts-de-Seine department (France) to provide all inhabitants with an equal level of protection against heavy-rain induced flooding events.

This implies to fairly assess the functioning of the sewage system against the severity of observed rainfall events, which raises the following scientific questions: how to rate the severity of a specific observed rainfall event? How to summarize the rainfall severity of a past year as a whole? To answer these questions we developed an approach based on previous studies (Ramos et al., 2005 and 2006), introducing a realistic and useful overall rate of the rainfall severity of a year over a sewer water management area.

## KEYWORDS

Assessment, geostatistics, rainfall hazard, simulation.

# 1 INTRODUCTION

A general concern for public authorities is to provide all inhabitants with an equal level of protection against heavy-rain induced flooding events. This raises the following scientific questions: how to rate the severity of a specific observed rainfall event? How to summarize the rainfall severity of a past year as a whole?

Descriptive statistics usually evaluated to build IDF curves and ARF coefficients are enough to set up a geostatistically-based simulation model. The output of such a simulation model has the main advantage that simulated fields have an exhaustive spatial coverage, as radar images, yet with exactly the same statistical properties observed in point data sets from rain gauges. This enables a direct estimation of IDF and ARF curves, and also an investigation of other features like the probability of simultaneous rain over given sub-basins, as well as of non-linear features like the occurrence of local maxima somewhere in a given area, named epicentrage analysis.

The approach adopted in this article follows those presented in Ramos *et al.* (2005 and 2006), with a particular development for the case of the department of the Hauts-de-Seine (175 km²). Data from 7 rain gauges for the period 1993-2003 is used in the analysis. Only the season of heavy rainfall risk is studied. Non-zero rainfall for durations from 5 minutes to 24 hours is fitted to Inverse Gaussian distributions, an asymmetric probability distribution function that allows to model both ordinary non-zero rain and realistic extreme intensities contributing to point IDF curves. The structural analysis of rainfall fields concludes to a double spherical model considering both local and regional variability. Rain / non-rain transition is taken as a non-zero rain probability with given spherical spatial structure.

The information obtained from simulated fields is the basis to produce severity diagrams to 97 selected rainfall events over the 10-year study period. For each event estimates are gathered into an overall rate. Events within a year were then gathered providing an overall rate per year. Gathering rules were inspired from experimental physiologic rules like the Fechner rule about the perception of sound, or the logarithmic Richter scale for earthquakes. The results in terms of event-rates and year-rates of severity were considered realist by local actors.

# 2 STOCHASTIC DESCRIPTION OF RAINFALL

## 2.1 IDF curves and ARF factors

Heavy rainfall studies are often merely an assessment of local intensity-duration-frequency curves (IDF). The consideration of spatial aspects is limited to describing a possible shift of the parameters of IDF curves in space or to assessing a set of areal reduction factors (ARF) relating statistics of basin rainfall to the IDF quantiles, which are point statistics representative of a rain gauge.

Rainfall point distributions and spatial variability can be studied for a chosen set of rainfall durations by ways of statistical and variographic analyses, provided data from a network of rain gauge is available over some years.

## 2.2 Modelisation

Point descriptive statistics and spatial correlation functions are enough to set up a geostatistically-based simulation model. The output of such a simulation model has the main advantage that the simulated field has an exhaustive spatial coverage, as is the case of radar images, yet with exactly the same statistical properties observed in point data sets from rain gauges.

This enables a direct estimation of IDF and ARF curves, which could possibly be derived from descriptive elements via mathematics, but also enables to investigate other features of direct engineering and water management interest like the probability of simultaneous rain over given sub-basins (see Ramos *et al.*, 2006 for details on the methodology for modelling and simulation of rainfall fields).

# 3 CASE STUDY

## 3.1 Data

The scientific approach adopted is demonstrated in the case of the department of the Hauts-de-Seine (175 km²). Data from 7 rain gauges for the period 1993-2003 is used in the analysis. Only the season of heavy rainfall risk is studied, which basically corresponds to the summer period specially for short durations (the convective rain season).

Rainfall distributions for durations from 5 minutes to 24 hours are fit to inverse Gaussian distributions, an asymmetric probability distribution function that allows to satisfactorily model the distribution of non-zero rain, as well as to simulate realistic extreme intensities, represented in IDF curves.

The structural analysis of the spatial variability of rainfall fields concludes to a double spherical model considering both local and regional variability. Rain / non-rain transition is also studied and taken into account in the form of a non-zero rain probability and a simple spherical function describing the spatial structure.

## 3.2 Simulation output

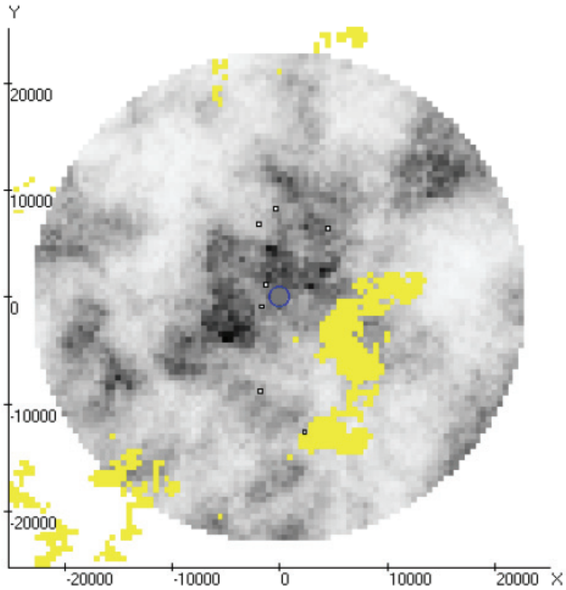
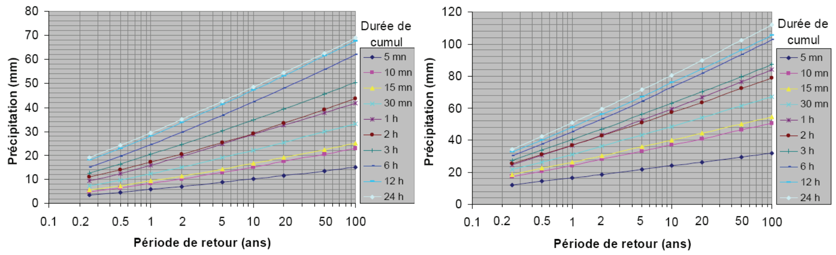



Fig 1 - A simulated hourly rainfall field over the Hauts-de-Seine department area

Once set up, the simulation model (Fig.1) was run to provide enough simulated fields to directly estimate any kind of areal maximum distributions: point (i.e., zero area), basin rainfall and areal maxima anywhere inside a given area. The stabilization of the quantiles was also verified in the simulation procedure.

An advantage of the simulation is that it provides a insight and an assessment technique to puzzling non-linear features like how often one in charge of the stormwater management of a territory will observed heavy rainfalls of locally rare occurrence (Fig. 2).




Local rainfallMax rainfall over 175 km²

Fig 2 - Comparison of local and areal estimates of rainfall. Example: at any given point the 10-year, 1-hour rainfall is 28 mm (graph on the left). Such a rainfall amount is however observed twice a year somewhere in the 175 km² domain (graph on the right).

# 4 ASSESSMENT OF PAST EVENTS

## 4.1 Individual events

The information obtained from the analysis of the simulated fields allows to qualify every characteristic in an observed rainfall.

According to the methodology adopted in previous studies (Ramos *et al.*, 2005 and 2006), a specific severity map is built to each of the 97 heavy rainfall events detected over the 10-year study period (Fig. 3). An illustrative diagnosis of where and over which duration each event could be considered severe is obtained (Fig. 4).

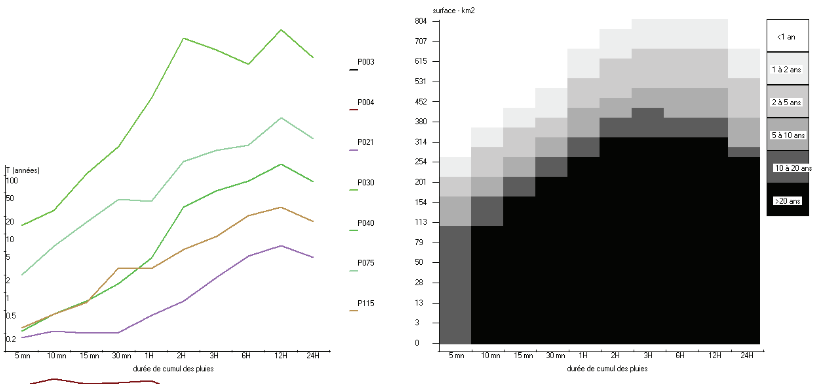



Fig 3 - Severity analysis of the event of 06-07, July, 2001

Severity Graph | Severity Diagram
Plot : one line per raingauge | Plot : max of return period over area
Axe X : rainfall duration | Axe X : rainfall duration
Axe Y : return period | Axe Y : Area (km²)

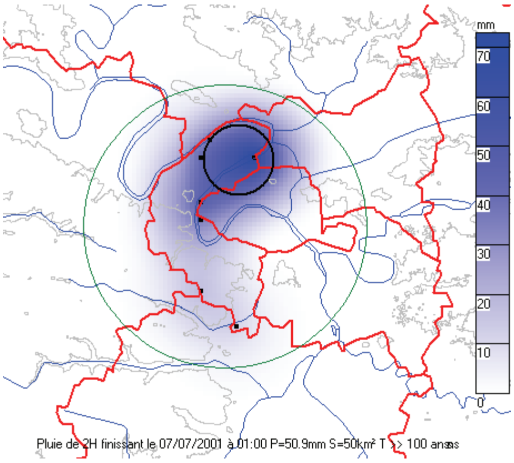



Fig 4 - The dominant feature in the event of 06-07, July, 2001: 51mm rainfall accumulated in two hours in a circle of 50 km². The return period, given the survey domain, is greater than 100 years.

For each event, the estimates were gathered into an overall score. For all cells in the severity diagram with non-zero area, the area rainfall is weighted by the logarithm of the area.

The global indicator considered is the sum of the average and the standard deviation of these values

The event illustrated in Fig 4 gets score 223.7, the highest score among the 97 events under study.

## 4.2 Global heavy rainfall assessment for a given year

Experimental physiologic rules like the one by Fechner about the perception of sound, or the logarithmic Richter scale for earthquakes, were considered as a basis for gathering the events within a year and providing an overall rate per year.

The results obtained for the years 1993 to 2003 are presented (Table 1). This way to aggregate the severity diagram into one only index and the method adopted to calculate observed rates for individual events or individual years gave values which reflect correctly the annual rainfall climatology. The indexes obtained were considered realistic by local actors, reflecting their own field experience.

| 1993 | 1994 | 1995 | 1996 | 1997 | 1998 | 1999 | 2000 | 2001 | 2002 | 2003 |
|---|---|---|---|---|---|---|---|---|---|---|
| 10.1 | 10.7 | 8.0 | 5.4 | 12.4 | 5.5 | 11.7 | 12.4 | 15.0 | 8.0 | 10.9 |

Table 1 . Yearly severe rainfall index in the Hauts-de-Seine department ; 0=lowest 20 = highest

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